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6. AUTHOR(S)
Edward E. Smith

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Michigan
Department of Psychology
East Engineering
Ann Arbor, MI 48109-1109

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13. ABSTRACT (Maximum 200 words)
The major purposes of our grant were: (a) to develop a psychological model of human reasoning in situations in which people are told some facts and then have to assign probabilities to generalizations of these facts; and (b) to use this model to develop "reasoning prosthetics," i.e., automated procedures that enable an individual reasoner to increase the accuracy of his or her probability judgments while remaining faithful to one's core intuitions. With respect to our first goal, we developed and tested the Gap model, which assumes that people's probability judgments about a domain are mainly based on their perceived similarity relations among objects in the domain, and on their intuitions about the plausibilit of object-predicate relations in the domain. Quantitative versions of the Gap model were shown to do an adequate job of predicting people's probability judgments. With respect to our second goal, we have developed a number of reasoning prosthetics, eac of which can reliably predict people's actual probability judgments, and in some cases more accurately match the true probabilities than can people's judgments. Othe topics in reasoning and probability judgments were also studied.

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"Development and Application of a Model of Individual Decision Making"

Edward E. Smith

Department of Psychology
University of Michigan
1250 East Engineering
Ann Arbor, MI 48109

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Prepared for:

Marilyn J. McKee
Air Force Office of Scientific Research
110 Duncan Ave., Suite B115
Bolling Air Force Base, D.C. 20332-6448

Final Technical Report for AFOSR Grant #94-0265

(6/1/91 - 10/31/94)

"Development and Application of a Model of Individual Decision Making"

The major purposes of our grant were: (a) to develop a model of the psychological processes that underlie human reasoning in situations where people are told some facts and then have to assign probabilities to generalizations of these facts; and (b) to use this model to develop "reasoning prosthetics," i.e., automated procedures that enable an individual reasoner or decision maker to increase the accuracy of his or her probability judgments; in addition, (c) we have extended our research on reasoning and probability judgment in a few directions that we did not anticipate in our initial proposal. In what follows, we consider research related to each of these three goals in turn.

1. Development of a Psychological Model of Reasoning

Consider the situation in which a person is given a fact and then asked to assign a probability to a generalization of that fact; this situation is equivalent to evaluating an argument in which the given fact is the premise of the argument and the generalization is the conclusion of the argument. Hence, our research is about the evaluation of arguments. We have focused on the evaluation of category-based arguments, which have the following form:

Some members of Category C have Property P

Therefore other (all) members of Category C have Property P.

Initially we emphasized cases in which the categories were familiar ones, like "lions," the properties or predicates were familiar enough to reason about, like "have skins that are more resistant to penetration than most synthetic fibers," and the subject's task was to judge the probability that the conclusion is true given that the premises are true. A sample item is:

Housecats have skins that are more resistant to penetration
than most synthetic fibers

Therefore lions have skins that are more resistant to
penetration than most synthetic fibers

In the first two years of the grant period, we developed a model of category-based judgments that was an extension of our previous work on category-based induction (Osherson, Smith, Wilkie, Lopez, & Shafir, 1990). The model makes the following assumptions:

(1) Each category is represented by a set of attributes and values. The predicate (e.g., "have skins...more resistant...") potentiates a subset of the premise category's attributes (e.g., size), and is then associated with these attributes and values on them.

(2) The premise category (e.g., "Housecat") is evaluated to see if its values on the relevant attributes are at least as great as those assumed to characterize the predicate.

(3) If the premise category's values are less than those of the predicate (e.g., housecat's size is less than that of the predicate), the latter are scaled down. The predicate is modified in this manner to the extent the premise category is similar to the conclusion category. In cases where the premise category's values are equal to or greater than those of the predicate's, there is no modification of the predicate.

(4) To the extent the predicate's values are scaled down, the conclusion category's values are more likely to be at least as great as those of the predicate, and hence the conclusion is likely to be judged more probable.

The upshot of these assumptions is that, the more implausible the premise and the more similar the premise and conclusion categories, the greater the modification of the predicate and the more probable the conclusion. The model is referred to as the "Gap" model, and it is presented in detail in Smith, Shafir, and Osherson (1993) and Osherson, Smith, Myers, Shafir, and Stob (1994).

We have performed numerous experiments to test the Gap model. To illustrate, consider the set of experiments reported in Smith et al (1993). One study found support for the major qualitative assumptions of the model; the judged probability of a category-based argument increased with both the implausibility of the premise and the similarity of the premise and conclusion categories. A second experiment showed that a quantitative version of the Gap model could satisfactorily fit the data of individual subjects. In the third experiment in this set, in addition to arguments in which the categories varied but the predicate remained constant, subjects also evaluated arguments in which the categories were fixed but the predicate varied. The result of this experiment were consistent with a minor variation of the Gap model. In other sets of studies, we have considered arguments in which both the categories and predicates vary. Again the Gap model was generally consistent with the data (Osherson et al., 1994; Osherson, Smith, Biolsi, Shafir, & Berthouzoz, in press).

2. Applications of the Gap Model

The Gap Model attempts to capture the mechanisms underlying human probabilistic reasoning, and it is evaluated by how well it manages to predict a person's judgment of argument strength. While human intuitive judgment can be remarkably insightful, it has the weakness of often being incoherent in the sense that it cannot be represented by numbers in a manner consistent with the probabilistic calculus. Thus, to the extent that the Gap Model approximates human reasoning, it is bound to generate normatively incoherent predictions.

To exploit the strength of human judgment while avoiding its weakness, it would be useful to develop a "reasoning prosthetic," a device that partly simulates human reasoning and partly corrects it, yielding assignments of numbers to propositions that constitute a genuine (i.e., coherent) distribution of probability while still approximating the intuitive probability judgment of the person providing the input. Such a device would facilitate the development of automated systems of reasoning based on probability and might also help in the development of expert systems (since it is well known that experts often have imperfect intuitions about probability).

We have used the Gap Model to develop such a reasoning device (Osherson, Shafir, & Smith, 1994; Osherson, Smith, Biolsi, Shafir, & Berthouzoz, in press). To see how to do this, consider the case in which the device receives as input an individual person's attribute-value ratings for objects and predicates, where these ratings can also be used to determine the similarity between objects in the domain and the similarity between predicates in the domain. In a first step, the Gap model is applied to the attribute-value vectors to produce probabilities for every argument of the form:

P1 P2 ... Pn / C,

where the Pi's and C are simple, object-predicate statements. These probabilities carry considerable information about the probabilities of arbitrary propositions and arguments. Since the Gap model is not guaranteed to produce coherent attributions of probability to such arguments, a second step is needed. In this step, linear programming is employed to produce a coherent distribution that minimizes the discrepancy with the numbers delivered by the Gap model (the linear programming technique is based on Franklin, 1980). This is the probability distribution posed by the reasoning prosthetic.

In our initial work on this project, we applied the above 2-step procedure and tested its output. We compared the probabilities the reasoning prosthetic assigns to arguments to a given subject's judgments about the same arguments. We determined that the prosthetic yields reasonably accurate predictions about the latter (correlations are on the order of .6 - .7). These predictions thus have three important properties: (a) they are probabilistically coherent, (b) they arise from attribute-value ratings, involving no probabilistic input from the subject, and (c) they are in rough conformity with the subject's probabilistic intuition (see Osherson et al., in press, for details).

In more recent work on this topic (Osherson et al., submitted), we have explored reasoning prosthetics that again are attribute-value vector representations, but are not derived from the Gap model. Again we have demonstrated that the predictions of the reasoning device are quite highly correlated with the probability judgments provided by real subjects. Furthermore, in cases in which the true probabilities can be determined (e.g., judgments about sporting events), we have shown that the reasoning prosthetic's predictions are more correlated with the true probabilities than are the person's. Thus, we can obtain some information from a person (e.g., the perceived similarity relationships between objects and between predicates in a domain), use this information to construct a reasoning prosthetic for that person, and then bootstrap an improvement in the judged probabilities. It is also worth noting that these results were obtained with arguments about more complex domains than the mammal arguments we used in many of our previous studies, e.g., domains of political conditions or weather conditions in various countries.

3. Other Directions

In addition to the research generated by our major goals, we also performed research in three related areas. This work is briefly described below.

(a) Evaluation of arguments with totally unfamiliar predicates

The preceding discussion deals with arguments in which the predicates are familiar enough to reason about. Some of our work during the grant period also dealt with category-based arguments in which the predicates were unfamiliar, biological properties that were unlikely to influence the reasoning process, predicates like "has sesamoid bones." In one project, we showed that several of the phenomena that have previously been found with adults reasoning about these kind of arguments also obtained with subjects as young as 7-year olds and with adults in non-Western cultures; this indicates that the strategies that people use to evaluate category-based arguments are natural ones rather than the products of schooling (Lopez, Gunthil, Gelman, & Smith, 1992; Lopez, Atran, Medin, Cooley, & Smith, submitted). In another paper, we showed that the standard phenomena obtained with unfamiliar predicates are more readily explained in terms of a similarity-based model than in terms of models that invoke rules or explanations (Smith, Lopez, & Osherson, 1992). This work isolates the importance of category relations in reasoning (such relations are only one component of the

Gap model); the connection of this work to that discussed in the main body of this report is amplified in Smith et al. (1993).

(b) Choosing a probability distribution

All of the preceding work touches on the issue of the coherence of probability attributions, i.e., whether such attributions are compatible with any probability distribution at all. In a recent paper (Osherson, Shafir, & Smith, 1993), we raised a different kind of issue. Consider a situation in which a person starts with a coherent set of probability attributions (say, a case where all the input information is presented numerically and consequently people can readily calculate some of the probabilities), and in which these probability attributions can be extended in more than one way to a complete distribution; what kind of extension is typically preferred by people? We proposed a number of psychological models for how people choose a distribution in situations like this, including the notion that people try to maximize the entropy in their chosen distribution (i.e., aside from taking consideration of the probabilities directly tied to the input information, the reasoner makes as few commitments as possible about the rest of the distribution).

(c) Biases in argument evaluation

The last project to be described looks at situations diametrically opposed to those that prompt coherent probability attributions, specifically, cases in which people judge the probabilities of arguments about social issues on which they take a definite position. An example of such an issue would be whether the death penalty is an effective deterrent to murder. Subjects who held either pro or con views about the issues evaluated arguments that were either pro or con the issues; for each argument, subjects essentially judged the probability of a conclusion given the premises. We found a striking bias: for a variety of social issues, people evaluated arguments compatible with their position as stronger than arguments incompatible with their position. Furthermore, people took longer to evaluate arguments incompatible with their position than those compatible with their position. This finding and others suggested that when people are confronted with arguments that are incompatible with their beliefs, they actively search for flaws in the argument; in contrast, when given an argument that is compatible with their beliefs, people are more likely to accept it at face value (Edwards & Smith, submitted).

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